Hierarchical Fully-Bayesian Inference for Combined EEG/MEG Source Analysis of Evoked Responses: From Simulations to Real Data

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Background
The reconstruction of brain networks by means of EEG/MEG recordings is still a challenging task for most current density reconstruction (CDR) imaging approaches. Recently, hierarchical Bayesian modeling (HBM) emerged as a promising CDR framework. Our work examines the performance of fully-bayesian inference methods for HBM for source configurations consisting of few, focal sources when used with realistic, high resolution Finite Element (FE) head models.

Data acquisition and Preprocessing
The following data was recorded from a healthy 25-year old male subject:
- Different MRI scans to build a realistic FE head model (see above).
- Auditory evoked potentials (AEP) and fields (SEF) by electrical stimulation of the median nerve (left/right hand, about 980 events each).
- CDR to an Equivalent Current Dipole (ECD) fit (based on the same 6 mm source model, its diagonal and an iid approximation. In Figure 1: Using an iid or diagonal noise covariance model (yellow curve, estimates nearly coincide) or the full noise covariance (blue curve). Right: ECD fits using an iid (red curve), diagonal (green curve) or full (blue curve) noise covariance model.

The full noise covariance matrix is estimated from the pre-stimulus interval. For the reconstructions, three different noise models are build from it: The full covariance matrix, its diagonal and an iid approximation. In Figure 1 we compare HBM-based CDR to an Equivalent Current Dipole (ECD) fit (based on the same 6 mm source reconstruction grid) for all noise models. Both methods show the same result for the full covariance model which is assumed to be the most accurate one (note that CDR do not limit the number of active sources explicitly!). HBM does not seem to be more sensitive to Gauss similarity than single ECD fits which are commonly used (Costenoble et al., 2011) to control and examine all steps involved:
- Noise estimation: Is HBM particularly sensitive to a misspecification or simplification of the noise covariance matrix?
- Comparing source reconstructions to atlas-based cortical segmentation
- Recalling source estimates for EEG, MEG and fMRI based reconstructions of the locations of auditory activity are regarded as more reliable than those of EEG-based reconstructions due to the better coverage of the characteristic magnetic field topographies in the sensor array (Panet and Lütkenhöner, 2000). Note that this is not reflected in the SNRs of this single subject. The MEG-based HBM reconstruction shows the expected bi-lateral sources in areas considered to contribute to auditory processing, a result similar to classical CDR fits. Interestingly, for this considered subject, the ECD-based HBM reconstruction is not too different from the MEG-based one aside from a slight shift in location and orientation. The MEG-based HBM reconstruction resembles the MEG-based one, a result consistent with the simulation studies in Figures 2 (left) and 3 (above).

Figure 1: Different source estimates for EEG-based reconstructions of somatosensory (N200m) activity, visualized by colored curves plotted with the white matter surface. Left: HBM Full-NM (Near-Means) estimates (see Luucka et al., 2012a) using an iid or diagonal noise covariance model (yellow curve, estimates nearly coincide) or the full noise covariance (blue curve). Right: ECD fits using an iid (red curve), diagonal (green curve) or full (blue curve) noise covariance model.

Conclusions
- Fully Bayesian inference for hierarchical Bayesian modeling can also give good source reconstruction results for real data and focal source scenarios.
- HBM is surprisingly robust against noise misspecification and residual background activity.

Motivation and Outline
In previous work (Lucoka et al., 2012a, 2012b) we compared fully-bayesian inference for HBM for EEG, MEG and EEG-MEG combination (EMEG) to established CDR methods by extensive simulation studies. Encouraged by the good results we proceeded to process first experimental data for simple, well-established source scenarios. We used somatosensory N200m (to test our methods for a single, superficial and mainly tangential source, while auditory N100(m) was used to test our algorithm for a more difficult scenario (bi-lateral sources near planum tempurale, Panet and Lütkenhöner, 2000).

In contrast to our expectations, the first results were quite unsatisfactory. Other researchers reported similar findings. Consequently, we wanted to better understand and improve our results. We build our own preprocessing pipeline with fieldtrip (Costenoble et al., 2011) to control and examine all steps involved:
- Noise estimation: Is HBM particularly sensitive to a misspecification or simplification of the noise covariance matrix?
- Comparing source reconstructions to atlas-based cortical segmentation
- Recalling source estimates for EEG, MEG and fMRI based reconstructions of the locations of auditory activity are regarded as more reliable than those of EEG-based reconstructions due to the better coverage of the characteristic magnetic field topographies in the sensor array (Panet and Lütkenhöner, 2000). Note that this is not reflected in the SNRs of this single subject. The MEG-based HBM reconstruction shows the expected bi-lateral sources in areas considered to contribute to auditory processing, a result similar to classical CDR fits. Interestingly, for this considered subject, the ECD-based HBM reconstruction is not too different from the MEG-based one aside from a slight shift in location and orientation. The MEG-based HBM reconstruction resembles the MEG-based one, a result consistent with the simulation studies in Figures 2 (left) and 3 (above).

Figure 2 (right): HBM Full-NM of auditory N100(m) activity. Source estimates for EEG, MEG and EMEG-based reconstructions are visualized by colored curves plotted with the white matter surface.

Outlook
- Comparing source reconstructions to atlas-based cortical segmentation
- Evaluating datasets from different subjects and for different source scenarios.
- Test stability of HBM reconstructions against SNR: Reconstruction of sub-sampled trial averages, comparison to trial-average averages.
- Data pooling to generate semi-artificial multiple-source scenarios.
- Develop automatic parameter choice rules for HBM.
- EEG/MEG combination requires a calibration of the head model conductivities, see Wolters et al., 2010.

References

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Realistic Head Modeling

Figure 3 (above): The first eigenvector of the conductive tensor scaled by the corresponding fractional anisotropy (FA) (Figure 1: left). Procedure to build a refined 3D/6D realistic anisotropic finite element (FE) head model. Components: Skin, gray and white matter, anisotropic conductivities are used, which have been computed from diffusion weighted MRI (2W-MRI) scans. A detailed description is given in Janssen et al., 2013.